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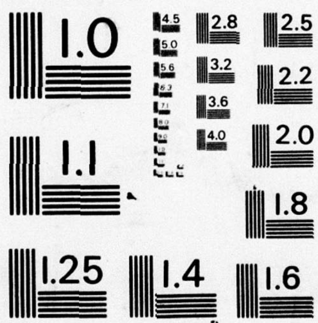

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CONDITIONS OF MODELING HEAT AND MASS EXCHANGE PROCESSES IN LOWER PRISM OF ROCK-FILL DAM IN CASE OF FORCED CONVECTION

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COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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The temperature-moisture regime in the lower prism of the dam is an important factor determining normal operation of rock-fill dams in regions with severe climatic conditions. In view of the difficulty of solving a system of differential equations which describes the processes of heat and mass exchange in the lower prism of the dam, the physical processes can be investigated experimentally on a model of the dam and then, using the modeling conditions, the results of the experiment can be transferred to the actual dam.

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CONDITIONS OF MODELING HEAT AND MASS EXCHANGE PROCESSES IN LOWER PRISM OF ROCK-FILL DAM IN CASE OF FORCED CONVECTION

Gor'kiy COLLECTION OF THE WORKS OF THE GOR'KIY CONSTRUCTION RESEARCH INSTITUTE in Russian [vol, date not given], pp 37-42

[Article by V. A. Zhdanov]

[Text] The temperature-moisture regime in the lower prism of the dam is an important factor determining normal operation of rock-fill dams in regions with severe climatic conditions.

In view of the difficulty of solving a system of differential equations which describes the processes of heat and mass exchange in the lower prism of the dam, the physical processes can be investigated experimentally on a model of the dam and then, using the modeling conditions, the results of the experiment can be transferred to the actual dam.

The conditions for modeling the temperature regime of earth dams are known [1, 2]. In the present article, on the basis of general modeling principles [3], we identify conditions for modeling air filtration and the processes of heat and moisture exchange, with due regard for phase transformations of the latter, in the lower prism of a rock-fill dam. It is considered that the movement of air in the pores of the fill has been established and is caused only by the influence of the wind on the lower slope of the dam (forced convection).

A unidimensional problem is considered in order to shorten the mathematical entries. Then the differential equations which describe the processes of heat and mass transfer in the rock fill can be written as follows [4, 5]·

$$\frac{\partial t}{\partial \tau} = \frac{\alpha_v}{(1-n)c_k\rho_k}(\theta - t) + \frac{L}{(1-n)c_k\rho_k} J_{(x)}, \quad (1)$$

$$w\frac{\partial \theta}{\partial x} = -\frac{\alpha_v}{c_g \rho_g}(\theta - t), \quad (2)$$

$$w\frac{\partial \rho_n}{\partial x} = \tilde{J}_n \quad (3)$$

$$-\frac{\partial p}{\partial x} = \frac{180 \rho_B \nu_B (1-n)^2}{\varphi d^2 n^3} w + \frac{2.25 \rho_B (1-n)}{\varphi d n^3} w^2 \quad (4)$$

$$J_n = -J_l(x), \quad (5)$$

where t_n and θ -- temperature of the rock and the air in the fill, degrees C.;

[illegible] -- specific heat capacity of the rock and air, gigacalories per kilogram, degrees C.;

ρ_n, ρ_B and ρ_n -- density of the rock, air, and water vapor, kilograms per cubic meter;

α_0 -- volumetric coefficient of heat exchange between the rock and the air in the fill, gigacalories per cubic meter/hour, degrees C.;

L -- latent specific heat of phase transformations of moisture, gigacalories per kilogram;

J_n and $J_{l(x)}$ -- source of vapor and ice (water), kilograms per square meter/hour;

t -- time, hours;

x -- axis coinciding with the direction of movement of the filtration current, meters;

w -- filtration velocity, meters per hour;

ν_B -- kinematic modulus of viscosity of the air, square meters per hour;

p -- excess air pressure, kilogram-force per square meter;

n -- porosity of the fill;

φ -- shape coefficient of the rock.

The mathematical expression of the conditions of similarity for the fields of different physical values for two similar systems is the following equality [3]:

$$\lambda_y = \frac{y_n}{y_m} \quad (6)$$

where y_m -- any value for the first phenomenon (on the model);

y_n -- a similar value for the second phenomenon (physical);

λ_y -- similarity constant or multiplier of a similar transformation (scale) of value y.

When modeling the processes of heat and mass transfer in the rock fill considering the phase transformations of the moisture contained in the air moving in the pores of the fill, air cannot be replaced by any other fluid in the model. If the temperature of the air at similar points of the model and the actual dam is the same, then other physical properties of the air at these points will also be the same. The model of the dam may be made of the same (chipped) material with the same shape coefficient as the physical dam. The porosity of the fill of the model and the actual dam can be taken as identical. Then all the similarity constants

which define the properties of the rock fill and the air moving in it will be equal to one:

$$\lambda_{\theta} = \lambda_{\rho_s} = \lambda_{c_s} = \lambda_{\nu_0} = \lambda_{L} = \lambda_{\rho_\kappa} = \lambda_{c_\kappa} = \lambda_{g} = \lambda_{\pi} = 1 \qquad (7)$$

Similar phenomena are described by the same differential equations, which makes it possible to establish the scale ratios of the various physical values needed for modeling.

The equation of movement (4) enables us to obtain the conditions of mechanical similarity of the two systems:

$$\lambda_{\ell} \cdot \lambda_{p} = \lambda_{w}, \qquad (8)$$

$$\lambda_{p} = \lambda_{w}^{2}, \qquad (9)$$

$$\lambda_{t} \lambda_{w} = 1 ; \qquad (10)$$

Substituting expression (8) into (9) we receive:

$$\lambda_{p} \lambda_{\ell}^{2} = 1 \qquad (11)$$

From equation (8) we obtain the following condition:

$$\frac{\lambda_{w} \cdot \lambda_{\rho_n}}{\lambda_{\ell}} = \lambda_{\gamma} \qquad (12)$$

According to condition (10) the scale is $\lambda_{w} = 1/\lambda_{\ell}$; therefore, expression (12) takes the form:

$$\lambda_{\gamma} = \frac{\lambda_{\rho_n}}{\lambda_{\ell}^{2}} \qquad (13)$$

If the quantity $\lambda_{\rho_n} = 1$, instead of condition (13) we have

$$\lambda_{\gamma} \lambda_{\ell}^{2} = 1 \qquad (14)$$

Using the heat transfer equations (1) and (2) we receive the conditions of heat similarity:

$$\lambda_{t} \lambda_{\alpha_0} = 1, \qquad (15)$$

$$\lambda_{t} \lambda_{\gamma} = 1, \qquad (16)$$

$$\lambda_{\alpha_0} = \lambda_{\gamma}, \qquad (17)$$

$$\lambda_{v} = \lambda_{\alpha_0} \lambda_{\ell} \qquad (18)$$

Considering equality (10) condition (18) takes the following form:

$$\lambda_{\alpha_0} \lambda_{\ell}^{2} = 1 \qquad (19)$$

Expressing the value λ_{α_0} from this and then substituting it into condition (15) we receive

$$\lambda_{t} = \lambda_{\ell}^{2} \qquad (20)$$

From both conditions (16) and (17) we find, after substituting expression λ_{y} (13) into them, that

$$\lambda_{p_n} = 1 \qquad (21)$$

It can be shown [6] that where wind velocity V = 2 meters per second, the excess pressure of the air in the lower slope of the dam, compared to *the pressure on the crest of the dam will be on the order of* $P_o^h = 0.2$ kilogram force per square meter (milimeters of the water column). If the model of the dam is 100 times smaller than the physical dam ($\lambda_{\ell} = 100$), which is convenient for conducting the experiment in laboratory conditions, according to condition (11) the pressure value P_o^h in the model should be

$$P_{\gamma}^{m} = \lambda_{\ell}^{2} P_{o}^{n} = 100^{2} \cdot 0.2 = 2{,}000 \text{ kG/m}^{2} = 2 \text{ m water column.}$$

It is very difficult to create such a difference in air pressure between the lower slope and crest of the dam model, and if we did achieve it the great drop in pressure would cause very high velocities of air filtration (100 times greater than physical one according to condition [10]) in the lower prism; in this case the sublimation ice which forms in the pores of the prism will swell outward through the crest of the dam, not settle on the rock surfaces within the prism, as it should be in reality. But to make the filtration velocities in the model little different from the physical ones the dimensions of the model dam must, according to condition (10), be large.

Thus, where condition (7) is observed the ratio of the similarity constants in modeling the processes of heat and mass transfer in a rockfill dam are determined by conditions (10), (11), (14), (19), (20), and (21). It follows from them that:

(1) the velocity of air filtration in the model should be as many times greater than the physical velocity as the linear dimensions of the physical thing are reduced;

(2) the air pressure, source of water vapor or ice (water), and volumetric coefficient of heat exchange in the model will be greater and the time of occurrence of physical processes less than in physical reality by the square of the reduction of the linear dimensions of the physical reality;

(3) the density of water vapor at corresponding points of the model and the physical reality should be the same.

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